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Designing for Sustainability: Lessons Learned from Four Industrial Projects

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Abstract. Scientific research addressing the relation between software and sustainability is slowly maturing in two focus areas, related to 'sustainable software' and 'software for sustainability'. The first is better understood and may include research foci like energy efficient software and software maintainability. It most-frequently covers 'technical' concerns. The second, 'software for sustainability', is much broader in both scope and potential impact, as it entails how software can contribute to sustainability goals in any sector or application domain. Next to the technical concerns, it may also cover economic, social, and environmental sustainability.

Differently from researchers, practitioners are often not aware or well-trained in all four types of software sustainability concerns. To address this need, in previous work we have defined the Sustainability-Quality Assessment Framework (SAF) and assessed its viability via the analysis of a series of software projects. Nevertheless, it was never used by practitioners themselves, hence triggering the question: *What can we learn from the use of SAF in practice?* To answer this question, we report the results of practitioners applying the SAF to four industrial cases. The results show that the SAF helps practitioners in (1) creating a sustainability mindset in their practices, (2) uncovering the relevant sustainability-quality concerns for the software project at hand, and (3) reasoning about the inter-dependencies and trade-offs of such concerns as well as the related short- and long-term implications. Next to improvements for the SAF, the main lesson for us as researchers is the missing explicit link between the SAF and the (technical) architecture design.

Keywords: Decision Maps, Sustainability-Quality Model, Design Concerns, Lessons Learned, Industrial Projects.

1 Introduction

With the ever growing pervasiveness of software-intensive systems, numerous questions arose on how to effectively and efficiently develop and maintain a

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software system. This led to the establishment of a vast corpus of knowledge on how to design, implement, and evaluate software-intensive systems. Still, to date, most efforts in software engineering focus on the optimization of technical aspects of software systems. Nevertheless, recently new researches emerged questioning: *what makes a software-intensive system sustainable? and what makes it contribute to sustainability?*

The growing research interest in the topics related to software sustainability led to the definition of *sustainability-awareness* as a software quality requirement. Such concept blossomed from the joint effort of academic researchers to define what it means for a software-intensive system to be sustainable e.g. [4, 9, 18, 22], and what role software engineering plays in its establishment [5, 6, 17, 20].

Following the definition of Lago et al. [18] and Venters et al. [22], software sustainability can be characterized in distinct yet interdependent dimensions. Based on such concept of sustainability dimension, Condori et al. [9] refined the definition of four core dimensions of software sustainability, namely the economic, technical, social, and environmental ones.

The four dimensions of sustainability are included in the Sustainability Assessment Framework (SAF) [10], a framework and accompanying toolkit[1] proposed to support data-driven reasoning and evaluation of the different sustainability dimensions which characterize a software-intensive system. The SAF is composed of three main components: the Sustainability-Quality (SQ) Model [9], the architectural decision maps [16], and the related suite of metrics [8].

Addressing sustainability in software engineering has a very broad scope, as illustrated by two manifestos [1, 12]. SQ assessment, in particular, is spanning from the assessment of software energy efficiency (e.g. [21, 23]) to the evaluation of the maturity of whole organizations with respect to Green ICT (e.g. [13, 14]). In this work we focus specifically on supporting software architects and design decision makers in the definition of sound SQ assessment. In this context, related works are relatively limited.

With a special focus on requirements engineering, Becker et al. [2] add *'individual'* as a fifth sustainability dimension in addition to the four sustainability dimensions used in this work. However, we argue that the social and individual dimensions share the same *social nature*. Furthermore, the first takes a broader perspective (e.g. organizations, society, stakeholder types), which is especially relevant in software architecture because it aims at capturing "the big picture". Considering the individual as an additional dimension is only appropriate when their concerns must be addressed. (e.g. in requirements engineering or human-computer interaction). Duboc et al. [11], in turn, define a framework for raising sustainability awareness and perform an evaluation that shows its effectiveness. This work can be seen as complementary to ours, by adding awareness creation as a first step followed by design decision making.

In order to create awareness on sustainability-quality requirements, we have conducted several empirical studies carried out with real-life projects in software companies [7, 10], but these studies focused only on the SQ model.

[1] SAF Toolkit, or Toolkit for short.

Finally, some works surveyed quality models and touched upon their relation to sustainability (e.g. [19]). Although still work in progress, to the best of our knowledge, our SAF Toolkit is the only providing concrete guidance for SQ design and assessment. Following previous validation of the SAF Toolkit [10], in this study we assess the experience of practitioners in applying it, with the dual goal of gathering their lessons learned as well as lessons to improve the Toolkit.

2 Background

The SAF was proposed to guide decision making from a software architect perspective. Of its components, the **Decision Maps (DMs)** essentially frame the *expected impact* of a software architecture on the relevant *sustainability concerns*. According to Lago [16], there are three types of *expected impacts*: *(i) Immediate impacts* refer to immediately observable changes. These are addressed within the current software project and are expected to be directly traceable to the architecture entities. *(ii) Enabling impacts* arise from use over time. This includes the opportunity to consume more (or less) resources, but also shorten their useful life by obsolescence or substitution. *(iii) Systemic impacts* refer to persistent changes observable at the macro-level (e.g. behavioral change, economic structural change).

The types of *sustainability concerns* reflect the corresponding four sustainability dimensions: *(i) Technical dimension* addresses the long-term use of software-intensive systems and their appropriate evolution in an execution environment that continuously changes. *(ii) Economic dimension* focuses on preserving capital and economic value. *(iii) Social dimension* focuses on supporting current and future generations to have the same or greater access to social resources by pursuing generational equity. For software-intensive systems, this dimension encompasses the direct support of social communities, as well as the support of activities or processes that indirectly create benefits for such communities. *(iv) Environmental dimension* aims at improving human welfare while protecting natural resources. For software-intensive systems, this dimension aims at addressing ecologic concerns, including energy efficiency and ecologic awareness creation. The relationships among design concerns are defined as *Effects*. We have three types of effects: *positive*, *negative*, and *required*. A legend of the visual notation used in the DMs is shown in Fig. 1.

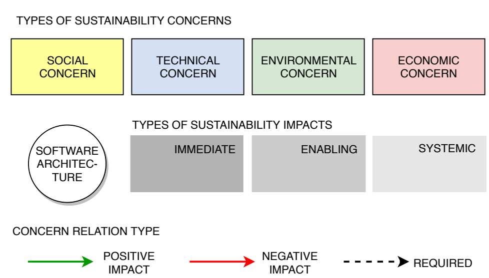


Fig. 1: Legend of the DM visual notation

Based on the ISO/IEC 25010 Standard [15], the **SQ Model** is made of a set of *Quality Attributes (QAs)* classified in the four sustainability dimensions, e.g. security in the technical dimension, energy efficiency in the environmental one. The QAs can be dependent. Such *dependency* can be of two types: (i) *inter-dimensional*, if it relates a pair of QAs defined simultaneously in two different dimensions (e.g. security defined in the *technical* dimension can influence security in the *social* dimension), and (ii) *intra-dimensional*, if a dependency exists between two different QAs defined within the same dimension (e.g. in the *technical* dimension, security may depend on reliability). Each QA of the SQ model is characterized by being measurable via a set of metrics.

The SQ model, as an Toolkit instrument, provides support to identify (i) sustainability concerns, and particularly those related to QAs; and (ii) the types of effect by means of the dependencies among QAs. In order to facilitate the creation of a DM, the following Toolkit instruments were created:

– A list of QAs in the SQ Model with their corresponding definitions and contributions to one or more sustainability dimensions [9].
– A set of dependency matrixes, representing the inter-dimensional dependencies in the SQ model.
– A decision graph, facilitating the correct identification of the types of impact.
– A custom library for the Draw.io editor tool[2], used to draw the DMs (see Fig. 3) according to the visual notation in Fig 1.

3 Study Design and Execution

In this section we document the design of our study and the details of the study execution. The focus of our study is to apply the SAF to concrete software innovation projects, with the goal of gathering lessons learned from both practitioner and researcher viewpoints. To do so, we carried out a set of working sessions, taking place over a week during the first graduate winter school *"Software and Sustainability: Towards an ethical digital society"*[3] at the Vrije Universiteit Amsterdam. In total, 6 participants were involved in the study, all with a consolidated industrial experience, ranging from 6 to 31 years, in sectors related to ICT and sustainability. The participants were involved in all steps of our study reported below, which constitute the outline of our study design. To gather data on the application of the SAF, we conducted educational sessions to provide participants with a sound understanding of the SAF and related concepts. Subsequently, participants applied the framework to concrete software innovation projects they were currently involved in. More in detail, the design of our study can be decomposed in 6 distinct steps, namely (i) preliminary familiarization with the topic of sustainability, (ii) introduction to the SAF toolkit, (iii) familiarization with the toolkit via a predefined hands-on example case, (iv) feedback on the example case execution. An eagle-eye overview of the process followed for our study is reported in Fig. 2, while the single steps composing the process are described in detail in the following.

[2] https://www.draw.io [3] https://tinyurl.com/yxemrk6c

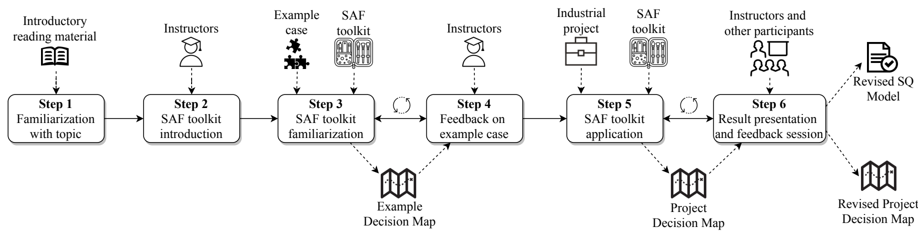


Fig. 2: Overview of the study design and execution

Step 1: Familiarization with the topic. In this preliminary phase, participants were invited to study a small set of introductory material (i.e. [9,16]), in order to get accustomed with the topics of ICT sustainability and the SAF prior to the first session.

Step 2: SAF Toolkit Introduction. In order to ensure that all participants possessed a sufficient level of background knowledge prior to the application of the SAF toolkit, two frontal lectures on the topic of sustainability and the SAF were conducted. Specifically, the first lecture focused on providing a sufficient level of knowledge on the notion of sustainability in software-intensive systems, with particular emphasis on the different dimensions of software-sustainability [18], how the dimensions can vary across different systems, and how the dimensions can impact positively and negatively our society. The second lecture instead focused on the introduction of the SAF and related concepts, with the goal of providing participants with sufficient knowledge to concretely apply the SAF toolkit. The lectures lasted a total of 3.5 hours, and were carried out in an interactive fashion, i.e., by actively engaging participants in discussions via questions and requests for feedback. The involvement of participants in discussions allowed to ensure, in a lightweight and informal fashion, their assimilation of the presented concepts.

Step 3: SAF Toolkit Familiarization. After the establishment of a common background knowledge on the SAF, a preliminary phase of familiarization with the framework was carried out. In this step, the participants analyzed via the SAF toolkit an example case, detailing a software-intensive system implementing a school enrollment management process. Specifically, participants were divided into groups, in order to let them jointly work on the example case. This let participants independently apply their newly acquired knowledge of the SAF for the first time. During this phase, instructors were only marginally involved, e.g. to clarify doubts on the application of the SAF toolkit. The minor intervention of instructors during this phase was purposely enforced, in order to let participants critically think about the SAF toolkit application. At the end of this step, each group was required to produce an example decision map, i.e., a decision map of the example case generated by applying the SAF toolkit.

Step 4: Feedback on Example Case. Subsequent to the generation of the examples decision maps, a feedback session involving both participants and instructors was carried out. During this phase, each group of participants presented the example decision map they worked on, and the results were jointly discussed with the instructors. Instructors provided feedback on the example decision maps, followed by further guidance on how to refine the application of the SAF. In order to ensure that participants fully assimilated the SAF analysis process and the details entailed by its application, Steps 3 and 4 were repeated two times. This constituted a feedback loop in which participants refined their skills over two days, by working on the same example project and perfecting their example decision maps according to the feedback of the instructors.

Step 5: SAF Toolkit Application. After the participants refined their skills by applying the SAF to the example case, they proceeded to analyze via the SAF toolkit a concrete industrial project. As introductory phase of this step, participants were asked to pitch, through a short presentation, a concrete industrial project they are working on. This provided participants with the possibility to carry out the SAF analysis on a project they were interested in and familiar with. Additionally, such project selection process allowed to collect real-life data on the practical application of the SAF to industrial projects. In total, four working groups were formed during this preliminary phase. Each group worked on a shared industrial project, as further discussed in Section 4. The output of this phase consisted of a preliminary decision map for each industrial project considered. In the eventuality that participants felt the need to carry out adjustments of the SQ model to better fit their project, they were instructed to note down their modification, in order to discuss them in Step 6.

Step 6: Results Presentation and Feedback Session. Similar to the application of the SAF toolkit to the example case, its application to the industrial projects was characterized by a feedback loop. Specifically, in order to refine the project decision maps created in Step 5, ad-hoc sessions were carried out. During such sessions participants presented their results, and got feedback on how to use the SAF toolkit, and correct / refine their decision maps. Both instructors and participants discussed each decision map, in order to make the result discussion a collective educational experience. Steps 5 and 6 were repeated two times, resulting in a revised project decision map per group (see output in Fig. 2). Additionally, adjustments that were done by the participants to the SQ Model during Step 5, were jointly discussed in the last feedback session, leading to the refinement of the SQ Model itself.

4 Projects and related Results

This Section presents the four industrial projects with the lessons learned from practitioners from their DMs (Sections 4.1-4.4) and the SQ Model (Section 4.5).

4.1 Project P1: *Sustainable Tourism in Indonesia*

Project Description The Indonesian Government wants to create an online platform to share and analyze data for transitioning toward a sustainable tourism. This should facilitate information exchange, monitoring and data-driven decision making for all relevant stakeholders (e.g. ministries, Statistics Indonesia, state energy companies, touristic organizations).

Currently, Indonesia is witnessing great economic growth thanks to tourism, but it lacks policies and regulations to ensure tourism' social and environmental sustainability. Data sharing among the key stakeholders is not supported or enforced; the government carries out time- and effort-consuming manual surveys to collect information; and understanding of the important issues is limited.

In this project, the *sustainability goal* is to identify the network of design concerns that help balancing economic growth and social/environmental sustainability of the tourism sector in Indonesia.

Project DM (Fig. 3a) The most important design concerns (required by this project to be successful) are interoperability, adaptability, and the definition of law and regulations that boost stakeholder engagement. By analyzing the network of dependencies captured in the DM, in short-term we expect these three concerns to lead to greater impacts on other aspects, for instance (technical) usefulness, (economic) efficiency and (social) accountability. In turn, for the long-term this will affect all of the sustainability dimension. Despite the social risk related to the use of big data by stakeholders, the accomplishment of this project will be strategic for the Indonesian Government to contribute to achieving SDGs 6 (Clean Water), 7 (Clean Energy), 8 (Decent Work and Economic Growth), 11 (Sustainable Cities), 13 (Climate Change), and most importantly 17 (Partnership).

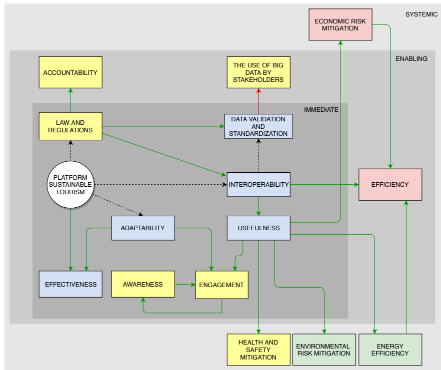
Lessons from the Practitioners

The Government is instrumental for engagement. The decision map shows that laws and regulations are necessary to trigger data sharing from the relevant stakeholders, which (thanks to interoperability and data standardization) can feed the platform with quality data automatically or semi-automatically. This will remove the need for manual surveys and the definition of guidelines for the various stakeholder.

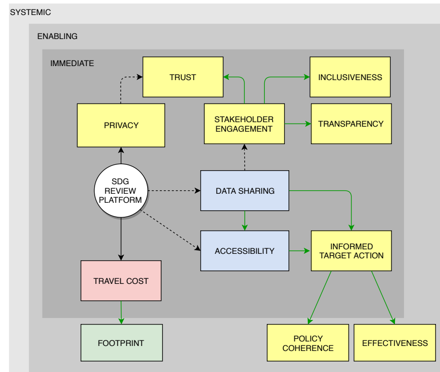
4.2 Project P2: *SGD Review Platform*

Project Description This project explores the potential effects of creating an online platform for the United Nations (UN) to gather and share the progress of the member states with respect to the global Sustainable Development Goals (SDGs, [3]).

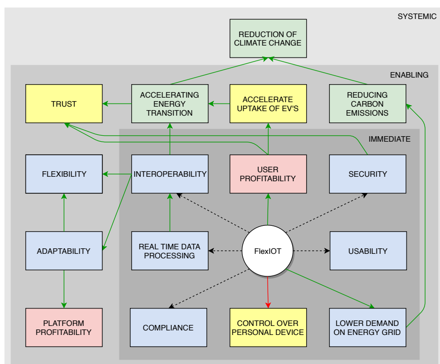
For the review of the progress towards the achievement of the 17 SDGs of the 2030 Agenda on Sustainable Development, an online platform could help to



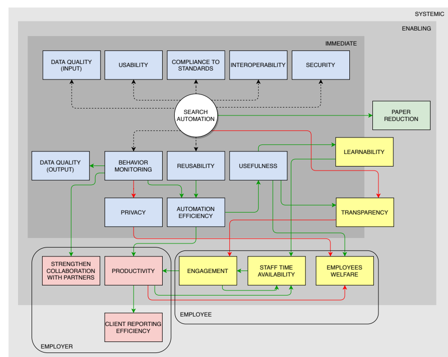
(a) DM of *"Sustainable Tourism in Indonesia"*



(b) DM of *"SGD Review Platform"*



(c) DM of *"Energy Provisioning via Flexible IoT"*



(d) DM of *"Search Automation for Literature Review"*

Fig. 3: Overview of the Architectural DMs of the industrial projects

compare across sectors, countries and over time. Countries already present their voluntary national reports (VNRs) at the annual High-Level Political Forum on Sustainable Development (HLPF) in New York. Reviewing the progress towards sustainable development is necessary in order to see if countries are on track, if more or other measures are needed and where challenges continue to exist. A virtual platform could help to show a bigger picture over time and could allow different stakeholders to feed their data. The collection and quality of data is still challenging which hinders significant comparison and, in turn, the creation of effective actions and policies. In addition, factors hindering the creation of such online platform include the non-trivial need for global accessibility from all member states, and the creation of trustful data sharing on a global scale.

In this project, the *sustainability goal* is to identify the network of design concerns that help balancing the technical needs for global data sharing and accessibility, and the social concerns related to privacy, engagement, inclusiveness, and coherent and targeted policy-making.

Project DM (Fig. 3b) The design concerns are mainly of a social nature, such as the the engagement of different stakeholders (governments, non-governmental organisations) who can use the platform which leads to effects on inclusiveness and transparency. Other concerns refer to privacy issues that are touched through the collection and provision of data. There are technical concerns related to the accessibility of the platform to make sure data can be fed into the platform.

Lessons from the Practitioners

Social sustainability is crucial. The DM emphasizes that the number of potential positive effects on the social dimension is significantly higher than expected. This is of two types, the effect on privacy (being both positive thanks to ensuring it via the platform mechanisms, and negative due to the need to share data) and the need for engaging all relevant stakeholders.
UN meetings could be complemented by virtual meetings. A co-product of a successful online SDG Review Platform is that the meetings in New York could be complemented by virtual meetings and lead to more frequent exchanges between stakeholders. The extent to which the platform could trigger this change is uncertain. If this would happen, the effect of replacing physical- with virtual meetings is expected to have a significant lower footprint.

4.3 Project P3: *Energy Provisioning via Flexible IoT*

Project Description This project analyzes the sustainability concerns relevant for FlexIOT, a platform that manages the use of decentralized IoT-enabled assets (like the batteries of electric vehicles, heat pumps, or cooling systems) in order to balance supply and demand on the Dutch national high-voltage energy grid.

To accelerate the energy transition and reduce carbon emissions, we must replace fossil fuel plants with alternative solutions that use renewable resources and are equally reliable. Access to IoT-enabled assets owned by prosumers, however, requires their trust, profitability for all parties involved, and flexibility in terms of both adaptability and scalability, among others.

In this project, the *sustainability goal* is to identify the network of design concerns that help balancing the technical flexibility of energy provisioning with IoT-enabled assets, and the need for inspiring trust and enabling behavioral change.

Project DM (Fig. 3c) Most of the design concerns of immediate impact are of a technical nature as the technical functionalities of FlexIOT are essential to its existence. However, the DM also highlights two user-related concerns which are required for the long-term sustainability of the platform: (i) gaining the trust of the prosumers (concern that depends on the extent to which other multiple concerns are addressed – see the incoming effect-arrows), and (ii) guaranteeing immediate profitability for the prosumer.

In this respect, the trade-off for the prosumer is a minimized loss of autonomy in the usage of his/her shared device. Psychologically, consumers experience the reduction of such autonomy as a big risk. Hence, experience shows that we must address two important concerns: (i) it is essential to mitigate this perceived risk by applying a financial reward (even if this is not enough to counteract the negative effect of a loss of autonomy); and (ii) the platform must create (social) trust by showing proof of the (technical) security it ensures. To this end, FlexIOT uses blockchain technology to handle all consumers data.

The ultimate systemic goal of this project is to reduce climate change by applying a reliable alternative to fossil fuel plants. This can be effectuated by FlexIOT, which is able to control an exponential number of assets by adding different asset-types. Making flexible assets profitable for prosumers, reduces the barrier to purchase an IOT-enabled device, resulting in a faster uptake of these assets, and finally an acceleration of the reduction of carbon emissions.

Lessons from the Practitioners

Trust is a decisive concern. The longevity of the system relies on its log term profitability for the operator. This can be achieved through interoperability, which effects both the flexibility of the system, and it's adaptability. Meaning the system is able to both control different assets, as well as accept input from different systems in order to control these assets.
Interoperability is an essential growth enabler. Interoperability is positively affecting both adaptability and flexibility (the latter further enforced via adaptability). This shows that this technical requirement of the system is essential, as adaptability is crucial for the scalability of the platform, and hence its economic profitability.

4.4 Project P4: *Search Automation for Literature Reviews*

Project Description This project explores the socio-economic sustainability of a tool supporting researchers in performing literature reviews for external clients. The tool relies on machine learning algorithms trained on logged data about the manual search behavior of researchers. In the short term, it can provide them assistance by suggesting highly relevant papers or search terms; in the long term, it can (partially) automatize searches in suitable technical fields or for specific review studies, hence potentially resulting in higher work efficiency and faster reporting to clients.

Monitoring the search behavior of researchers, however, is a prerequisite to train the tool. As the logs show precisely how researchers work, without proper data protection it could be potentially misused by the research institutes they work for, e.g. to pinpoint less efficient employees or enforce higher productivity targets.

In this project, the *sustainability goal* is to identify the network of design concerns that help balancing the economic interests of the employer (the research institute) and the employees' social concerns ensuring workplace wellbeing.

Project DM (Fig. 3d) As we can observe in Fig. 3d, the vast majority of immediate impact design concerns are of a technical nature including, among others, aspects related to data quality, automation efficiency, interoperability, and security. This highlights the core technical nature of this project. Interestingly, the DM clearly outlines that these technical concerns are expected to have an influence on other concerns belonging to different sustainability dimensions, of enabling and systematic impact.

Specifically, social concerns are characterized by an enabling impact, and are derived for the most part directly from the system's technical concerns. Such social concerns are related with the employees. Differently, also two economic concerns have an enabling impact, but this time the concerns are associated to the employer rather than the employee.

From the DM we can also observe how the project has a direct positive effect on paper reduction in the environmental sustainability dimension.

Finally, we can see that the only concern with a systemic impact is related to the economic dimension and reflects the end goal of the project.

Lessons from the Practitioners

Socio-economic concerns conflict between stakeholders. The DM emphasizes that the sustainability of the envisaged tool depends on the balance between the employees' social concerns, and the economic concerns of the organization. Such a balance is crucial to engage the employees. Given that the organizational culture is of ensuring employee welfare by rewarding employees for their dedication, an option is to equally reinvest the efficiencies resulting from automation in staff enrichment activities and economic productivity.

4.5 Revised Sustainability Quality Model

During the design of the DMs in the projects, participants could refine the SQ Model by creating ad hoc definitions of QAs specific to a sustainability dimension. In other words, participants could use either the standard definition of the QA provided in the ISO/IEC 25010 standard [15], or re-define the QA according to the specific sustainability dimension and the context of their project. Additionally, while an initial mapping of QAs to sustainability dimensions was provided to the participants (see coloured cells in Table 1), such mapping was not enforced, i.e., participants could add additional mappings according to their specific needs. In this section, we report the results of such process, which are schematically reported in Table 1.

As we can observe in Table 1, in 3 out of 4 projects the SQ Model was used to identify sustainability concerns and types of effects among related QAs.

Table 1: Sustainability-quality model analysis results (Colour = Mapping of QA to sustainability dimension, SP# = Standard definition of QA [15] used for project #, CP#-ID# = Custom definition ID# used for project #)

Characteristics	Attributes	Definition according to [6]	TECH	ENV	ECON	SOC
Compatibility	Interoperability	a system can exchange information with other systems and use the information that has been exchanged.	SP3			SP1
Context coverage	Flexibility	system can be used in contexts beyond those initially specified in the requirements.				CP3-1
Effectiveness	Effectiveness	accuracy and completeness with which users achieve specified goals.	CP4-1			SP1
Efficiency	Efficiency	resources expended in relation to the accuracy and completeness with which users achieve goals.				CP1-1
Freedom from risk	Economic risk mitigation	system mitigates the potential risk to financial status in the intended contexts of use.		SP3	CP1-2	
	Environmental risk mitigation	system mitigates the potential risk to property or the environment in the intended contexts of use.				SP1
	Health and safety risk mitigation	system mitigates the potential risk to people in the intended contexts of use.				SP1
Functional suitability	Functional appropriateness	the functions facilitate the accomplishment of specified tasks and objectives.	SP4			
	Functional correctness	system provides the correct results with the needed degree of precision.			SP4	
Maintainability	Modifiability	system can be effectively and efficiently modified without introducing defects or degrading existing product quality	SP4			
Performance efficiency	Time behaviour	response, processing times and throughput rates of a system, when performing its functions, meet requirements.	CP3-2, SP4			
Portability	Adaptability	system can effectively and efficiently be adapted for different or evolving hardware, software or usage environments.	SP3			
	Replaceability	product can be replaced by another specified software product for the same purpose in the same environment.				SP1
Satisfaction	Trust	stakeholders has confidence that a product or system will behave as intended.				CP3-3
	Usefulness	user is satisfied with their perceived achievement of pragmatic goals.				SP1
Security	Integrity	system prevents unauthorized access to, or modification of, computer programs or data.	SP3			
Usability	User error protection	system protects users against making errors.	CP3-4			

Participants of project P2 opted not to use the SQ model, as they deemed themselves not confident enough with the ISO/IEC 25010 standard to carry out the analysis. In total, 21 definitions of QAs were used, of which 14 by following the standard definition, and 8 using ad hoc definitions. The most frequently considered dimensions of the SQ Model result to be the technical dimension (9/21) and social one (9/21). The depth in which the technical dimension is considered reflects the emphasis on technical concerns which characterizes projects P3 and P4. Similarly, the high recurrence of QAs mapped to the social dimension can be traced back to the relevance of the social dimension in SP1. Overall, QAs were only marginally mapped to the economic and environmental dimension. Interestingly, the environmental dimension was mapped to a single QA, which was not identified in the technical-action-research with which the SAF was validated [10]. The findings of this study will be further considered in order to refine the SQ Model, by considering the feedback of the participants, their results, and the context of the projects. For completeness, the ad hoc definitions provided by the participants is documented in Appendix A.

5 Lessons to improve the SAF Toolkit

The following summarizes the most important lessons we as researchers have learned throughout the whole week and which will help us improving the Toolkit. In particular, at the end of Step 6 we collected general feedback from the participants, as well as our own general observations from the way the participants worked at their project. Our main lessons learned are:

- Project P2 showed the need to use the "requires" relationship between concerns, too. This suggests that sustainability concerns may have a mix of inter-dependent effects (that can be part of a sustainability measure) and requirements (that should be satisfied by the implemented system, with no measure attached). While this does not require major changes in the DM notation, it plays an important role when concrete metrics are assigned to SQ measurements.
- Due to their unfamiliarity with the ISO/IEC 25010 standard, participants of Project P2 did not make use of the SQ model. This points to the need of a more in-depth training on the standard and related concepts, in order to ensure that all participants possess sufficient confidence to carry out the analysis via the SQ model.
- Project P4 extended the DM notation by clustering the concerns from the two stakeholders that are in conflict. This extension helped framing the presence of the conflicting stakes, and highlighting the chain of positive and negative effects that need balancing. In general, this shows that different perspectives can be illustrated also within a single view illustrated by a DM. Accordingly, we learn that different stakeholder perspectives can be captured both within a DM (when e.g., the network of concerns is simple enough), and with multiple DMs, one per stakeholder, when the complexity of the network of concerns hinders reasoning and decision making.
- In spite of the diversity in both the various projects and the expertise of the participants, a generalized surprising factor was that the DMs helped uncover the hidden social-sustainability concerns. The participants all agreed that social sustainability is often left implicit while playing an instrumental role for achieving the target sustainability goals.
- In general, the participants all agreed that the Toolkit is a powerful instrument to (i) sharpen the design space, (ii) zoom out the details of the project at hand and gaining a broad perspective to spark *new* insights, (iii) facilitate informed choices, and (iv) communicate *what needs to be done* (including risks and benefits) with stakeholders with different concerns and expertise.
- The participants also agreed on a weakness of the Toolkit, namely the missing link between DMs and the (technical) architecture design views which are customary in software projects. We are happy to hear this as this is part of our ongoing and future research.

6 Conclusions and Future Work

This paper reports on a multi-case study where practitioners applied the SAF to four industrial cases. Our goal was to understand *What can we learn from the use of SAF in practice?* To this aim, we operationalized the SAF with the associated Toolkit instruments.

In spite of this being a single study with a relatively limited size (6 practitioners and 4 industrial cases), the results are very encouraging and suggest that the SAF can be readily used in practice, but that it needs further research (especially to define sound SQ metrics, and the explicit link between DMs and the (technical) software architecture elements and related views) to close the gap between design decision making and architecting.

The feedback we received from the practitioners indicates that the SAF helps them in (1) creating a sustainability mindset in their practices, (2) uncovering the relevant SQ concerns for the software project at hand, and (3) reasoning about the inter-dependencies and trade-offs of such concerns as well as the related short- and long-term implications. In addition, we could identify a number of lessons learned (described in Section 5) that will help us improving the SAF.

As future work we will continue training practitioners in using the SAF, with a dual benefit: they learn how to embed sustainability-quality in their software practices; we learn from them what needs to be included in the SAF Toolkit.

A Appendix: Custom Quality Attributes Definitions

CP1-1 (Efficiency): *"Resources expended in relation to the accuracy, completeness and also less cost/time/human resources to conduct the research"*.
CP1-2 (Economic Risk Mitigation): *"Mitigates risk to financial and economy for national/local level"*
CP3-1 (Flexibility): *"The system can be used in contexts beyond those initially specified in the requirements, such as controlling different assets"*
CP3-2 (Time Behaviour): *"Response, processing times and throughput rates of a system, when performing its functions, is real-time"*
CP3-3 (Trust): *"Users have confidence that a product or system will behave as intended."*
CP3-4 (User Error Protection): *"System protects users against making errors by being as intuitive as possible"*
CP4-1 (Effectiveness): *"Complies data quality requirements both in input and output"*
CP4-2 (Confidentiality): *"The system ensures that data are accessible only to those authorized to have access. Additionally, data should not be used for negative reporting, but only for improving efficiency."* Note: This QA was re-defined in Project P4 but not included in the corresponding DM.

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